DOCUMENT RESUME

ED 256 315 IR 011 635

AUTHOR Goetzfried, Leslie; Hannafin, Michael
TITLE The Effect of Adaptive, Advisement, and Linear CAI Control Strategies on the Learning of Mathematics Rules.
PUB DATE Jan 85
NOTE 28p.; Paper presented at the Annual Convention of the Association for Educational Communications and Technology (Anaheim, CA, January 17-23, 1985). For entire proceedings, see IR 011 621.
PUB TYPE Reports - Research/Technical (143) -- Speeches/Conference Papers (150)

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS *Computer Assisted Instruction; Grade 7; Junior High Schools; *Learning Strategies; *Mathematical Applications; *Mathematical Formulas; Mathematics Instruction; Mathematics Skills; *Pacing; *Remedial Mathematics
IDENTIFIERS *Learner Control

ABSTRACT

This study examined the effects of the locus of three computer assisted instruction (CAI) strategies on the accuracy and efficiency of mathematics rule and application learning of 47 low-achieving seventh grade students in remedial mathematics classes. The instructional task was a mathematics rule lesson concerning divisibility by the numbers two, three, and five. CAI treatments were an externally controlled adaptive strategy, an individually based learner control with advisement strategy, and a no-control linear design strategy. Dependent variables were immediate posttest and retention test scores for both rule recall and rule application; the time spent on the instructional task was also recorded. Teachers rated students on mathematics ability in relation to other seventh-grade students. Effects were examined for CAI strategy, prior achievement, and sex of student. Significant differences were found for achievement and the achievement by scale interaction, with the below average (above the 20th percentile) group yielding better rule recall and proportionately greater application scores than low (below the 20th percentile) students. The no-control linear strategy, however, required less time to complete and resulted in the most efficient treatment. Seventeen references are listed. (Author/LMM)

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The Effect of Adaptive, Advisement, and Linear CAI Control Strategies On the Learning of Mathematics Rules

Leslie Goetzfried
University of Colorado at Boulder
and
Michael Hannafin
Pennsylvania State University

Running head: CAI Strategies

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Abstract

The purpose of this study was to examine the effects of the locus of three computer-assisted instruction (CAI) strategies on the accuracy and efficiency of mathematics rule and application learning of low achieving seventh grade students. The three CAI treatments were an externally controlled adaptive strategy, an individually based learner control with advisement strategy, and a no control linear design strategy. Effects were examined for CAI strategy, prior achievement, and sex of student. Significant differences were found for achievement and the achievement by scale interaction, with the below average group yielding better rule recall and proportionately greater application scores than low students. The no control linear strategy, however, required less time to complete and resulted in the most efficient treatment.

The Effect of Adaptive , Advisement, and Linear CAI Control Strategies On the Learning of Mathematics Rules

In recent years many studies have dealt with various issues in computer assisted instruction (CAI). In general, CAI has been found effective in increasing performance, improving learner attitudes, and reducing time-on-task (Kulik, Bangert, & Williams, 1983; Kulik, Kulik, & Cohen, 1980). The locus of control in CAI design, learner, computer, or combined control, has been a recurring, but as yet unresolved, issue. The amount of control that learners can effectively manage, and the factors likely to affect control strategies, are not generally known.

Most studies which address instructional locus of control focus on either external program-level adaptive control (Ross & Rakow, 1981; Rothen & Tennyson, 1978; Tennyson & Rothen, 1977) or internal learner control with varying amounts of advisement (Ross, Rathow, & Bush, 1980; Tennyson, 1981; Tennyson & Buttrey, 1980). Adaptive computer control is typically regulated from within the program, dependent upon the learner's prior knowledge, accuracy of responses during the instruction, or lesson achievement status. Learner control usually incorporates a form of advisement, which informs the student about progress towards

mastery, and a prescription for full mastery (Tennyson & Buttrey, 1980). The procedural decisions during the instruction, however, are typically under individual learner control. Whereas several CAI control strategies exist, the relative effectiveness of various control strategies has not been studied.

Several factors are likely to influence learning from CAI. Prior student achievement was a key influence on the amount of instructional support needed for optimal learning (Tennyson & Rothen, 1977; Ross & Rakow, 1981). Students with high ability or prior achievement performed best under learner controlled instruction, while low ability students required the externally imposed program control. In 1981, Tennyson demonstrated that average and above average high school students effectively managed their CAI when provided continuous advisement as to achievement and instructional needs. It is not known to what extent such strategies affect the performance of younger or less able students.

The nature of the learning task is also likely to exert a controlling influence. Several authors have noted that effective rule teaching procedures require instances of rule information, application, and practice (cf. Scandura, 1972; Tennyson & Tennyson, 1977). The strategies for teaching rule use and application are different from those used to teach other skills (Gagne, 1977), and require study for computer-based instruction.

The influence of sex differences, especially related to

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mathematics, is also of importance (Armstrong, 1981; Benbow & Stanley, 1980; Fennema & Sherman, 1977,1978). Whereas such achievement differences may be diminishing (Levine & Ornstein, 1983), considerable controversy remains. If such differences are moderated by sociocultural influences, such as tacit teacher-student interactions, then CAI might be effective in controlling subtle biases. Presumed mathematics-related sex differences, and the influences of various CAI design strategies on such differences, should be considered.

Several empirical and practical issues related to the design and effectiveness of CAI warrant study. The purpose of this study was to examine the effects of externally versus internally controlled CAI design strategies on the mathematics rule learning, retention, and efficiency of low achieving junior high students.

Methods

Subjects

A total of 47 seventh grade students, enrolled in low-achievement remedial mathematics classes, participated in the study. Class placement was based upon poor performance on a standardized test, the Comprehensive Test of Basic Skills, which was administered eight months prior to this study. Students were drawn from a middle-class school system, consisting of a majority of Anglo and a minority of Hispanic and

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other ethnic group representation.

Instructional Materials

The instructional task selected for this study was a mathematics rule lesson concerning divisibility by two, three, and five. Each treatment consisted of the same basic tutorial CAI program, designed to teach the rules for divisibility by two, three, and five, and the application of these rules to five and six digit numbers. The lesson structure was based upon the "Events of Instruction," and adapted to CAI (Gagne, 1977; Gagne, Wagner, & Rojas, 1981). Three versions representing different CAI design strategies were developed.

Adaptive control. This version consisted of externally controlled CAI, during which the computer branched students for reteaching or more examples dependent upon the accuracy of responses during the lesson. Students completed the entire CAI program before exiting the lesson. Students had no control over the pacing or amount of teaching in the lesson. All control for this lesson was externally regulated through programming commands; students advanced only when correct responses were made and mastery levels were attained.

Learner control with advisement. This treatment consisted of internally controlled CAI, during which students were continuously advised of progress toward objectives, but permitted to determine if reteaching, additional examples, or additional problems were needed. Students were advised that they should answer at least four problems

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correctly before advancing to the next section. However, students were free to continue to the next rule at any time after the tutorial portion of each section.

No control. This treatment served as control for the study. Students using this strategy received the same sequence of instruction and examples but had no advisement, no individual control to review or to select additional examples, and no externally imposed program decisions based upon the accuracy of responses. Students were only able to control the pace of the instruction by advancing through the presentation when ready. This treatment was linear CAI, which permitted the student only to follow the predetermined instructional path. Each student was required to complete the entire lesson before proceeding.

Recall and Application Tests

Immediate posttest. A 25 item five-part multiple choice written posttest was administered to each student upon completion of the CAI program. The written test included eight questions which tested rule recall and 17 questions which tested the application of the rules for divisibility by two, three, and five. Recall questions required students to recall the test rules in various forms. Application questions required students to select the correct four, five, or six digit number which was divisibile by one or more of the test numbers. Test numbers of this size were chosen to assure that students could not easily determine the answer without applying the rule.

Parallel retention test. A parallel multiple choice test of 25 questions was given to test retention of rules and ability to apply rules learned from each CAI strategy. The parallel test was identical to the immediate test in form, item number, and item type. Each of the items included on this test was designed to mirror a corresponding item from the immediate test, except the numbers and context used to elicit the rule were different. The forms were validated for equivalence through a series of item evaluations conducted independently by two researchers.

The reliability of the achievement tests were established prior to the study by administering the immediate posttest, then the parallel retention test one week later, to 55 eighth grade students. The parallel form reliability of the test was .67.

Teacher Survey

For each student, the student's current mathematics teacher rated mathematics ability in relationship to other seventh grade students. A five part rating scale, with values ranging from low math ability to high math ability was used in this rating. The survey provided information about student mathematics capabilities to assure that all students selected for this study were below average mathematics performance.

Dependent Measures

Dependent variables were immediate posttest and retention test

scores for both rule recall and rule application. In addition, the number of minutes spent on the instructional task was collected for each student, and analyzed both separately and with test scores as an indication of learning efficiency. The learning efficiency score was a measure of the ratio of number of correct responses on each rule and application test, divided by the number of minutes required to complete the instruction.

Procedures

Standardized mathematics scores and teacher ratings were gathered for each student prior to the study. The 20th percentile was the median score for the 47 students, and was used to classify students as "below average" or "low" in prior mathematics achievement. Those students below the 20th percentile were classified as low, and those above the 20th percentile as below average, achievement for the purposes of this study. The teacher ratings were used to corroborate these classifications. In cases of inconsistency between teacher ratings and standardized test scores, student data were excluded from the analysis.

Prior to the study, the researcher provided general information to the students as to the purposes and expectations of the study. During this time the students were instructed in the elementary operation of the microcomputer to be used in the project and were given a short time to interact with another CAI lesson similar procedurally to the lesson used in the present study.

The students were randomly assigned to one of the three treatment groups, stratified to ensure that approximately equal numbers of males and females with low and below average achievement were assigned to each treatment. Students were directed to one of five microcomputer stations, and the corresponding CAI lesson was provided. Each student received a brief review of computer operation and was instructed to proceed with the lesson. At the conclusion of the lesson the elapsed time was noted and the immediate posttest was administered.

One week later students were given the parallel retention test in their classroom. Only students who were present during all phases of the study were retained for data analysis purposes.

All tests were scored using "blind" scoring procedures after the delayed retention test was completed. Separate scores were obtained for rule recall and rule application for each test administration.

Design and Data Analysis

This study used a 3 x 2 x 2 between subject factorial design with two additional within subject factors. The between subject factors included three levels of CAI strategy (adaptive control, learner control with advisement, and no control), two levels of achievement (low and below average), and sex of student. The within subject factors included test scale (rule recall and rule application) and test interval (immediate and retention).

Data were collected for each student on each of the two scales, for

both immediate and retention tests. In addition, time on task data were collected during instruction. A learning efficiency index, the ratio of test score to time on task, was also computed and analyzed.

Data were analyzed using MANOVA procedures for repeated measures designs. The MANOVA procedures were used to analyze the effects for rule recall and rule application as well as for learning efficiency. ANOVA procedures were used to examine effects for differences in time on task. Comparisons among treatment means were accomplished using Newman-Keuls pairwise contrast procedures.

Results and Discussion

Rule Recall/Rule Application Effect

The mean scores for rule recall and rule application scales for immediate and delayed tests are contained in Table 1. A significant difference related to prior achievement was found, $F(1,34)=16.74$, $p<.0005$. The below average students consistently scored higher than low students across all CAI strategies. In addition, a prior achievement-by-scale interaction, illustrated in Figure 1, was also detected, $F(1,34)=6.63$, $p<.01$. Below average students scored higher across both the rule and application scales, but proportionately higher on application items. No differences were found for CAI control strategy.

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As expected, a significant difference was also found between test intervals, $F(1,34)=6.31$, $p<.01$, which was characterized by a uniform decline in test scores over time for both treatments and scales.

Insert Table 1 and Figure 1 about here

Time on Task

A significant difference was found for CAI strategies, $F(2,38)=15.80$, $p<.001$. The no control strategy averaged significantly less time to complete (9.0 minutes) than both the externally controlled adaptive strategy (12.4 minutes), $p<.05$, and the internally based learner control with advisement strategy (16.3 minutes), $p<.01$. The time differences between the adaptive and advisement strategies were also significant, $p<.01$.

A significant effect was also detected for prior achievement, $F(1,38)=4.88$, $p<.05$. Below average students used less time to complete treatments (mean score = 11.35) than low achievement students (mean score = 13.96).

Learning Efficiency

The mean scores for learning efficiency are contained in Table 2. Several significant differences were detected. Learning efficiency differences were found for CAI strategy, $F(2,34)=6.41$, $p<.005$, and prior achievement, $F(1,34)=16.22$, $p<.0005$. The no control strategy was the

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most efficient (.70 concepts/minute), followed by the adaptive strategy (.51 concepts/minute), and the learner control with advisement strategy (.36 concepts/minute).

Although below average students were more efficient than low students, a significant interaction also was found between test scale and prior achievement, $F(1,24)=8.37$, $p<.01$. This effect is illustrated in Figure 2. The below average students were more efficient than low students on both scales, but proportionately better on applications.

Another significant difference was evidenced by the interaction between control strategy and test interval shown in Figure 3, $F(2,34)=3.64$, $p<.05$. The efficiency of the no control strategy treatment dropped significantly from the immediate to the retention test, while both adaptive and learner control strategy treatments remained more consistent in their efficiency. No other significant main effects or interactions were found.

Insert Table 2, Figure 2, and Figure 3 about here

General Discussion

Previous research has not addressed adequately the effects of

various CAI control strategies on the performance of low achievers. The purpose of this study was to examine the effects of the locus of control of CAI design strategies on the mathematics rule learning of low achieving junior high school students. The results indicated that low achieving students learn comparably under internal, external, and no control strategies, but perform most efficiently under imposed no control linear strategies.

Several points warrant discussion. The issue of achievement versus efficiency of learning was a key feature in this study. Whereas no differences were found for achievement resulting from the different design strategies, both instructional time on task and the associated acquisition rate were affected significantly. The adaptive and advisement CAI control strategies used in this study required greater learner time to complete, with no associated gain in learning. The basic linear design yielded comparable learning coupled with significantly less instructional time. Given these findings, a convincing argument can be offered for the functional superiority of simple linear design models for low achievers.

In previous studies, reported by Tennyson and associates, the increase in instructional time has proven worthwhile: learning for older and more able students was improved in direct relationship to the control strategy and amount of instructional time invested. The patterns obtained for the younger and less able learners in this study,

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however, may indicate that previous research on instructional control strategies is of limited generalizability for this population. Both the age and prior achievement characteristics of the present sample were intentionally different from earlier studies. The age and capability differences resulted in effects that were clearly different from those of earlier studies.

Performance differences may be attributable to several factors. Younger and less able students have less background knowledge in the content area of the instruction, and consequently are less effective in making judgements as to their progress and need for additional instruction. This background is required for effective interaction with learner controlled strategies. Strategies that continuously re-route learners through instruction that was inadequate in teaching concepts initially may also be undesirable. Low achievers may derive maximum benefit from the initial presentation of instruction, and may experience dissonance upon re-exposure to information not learned initially. In the present study, the comparable learning across CAI strategies suggests that little was gained by routing learners through either internally governed or externally controlled options.

Linear strategies, on the other hand, move learners through identical instructional paths, based upon the logical sequence of information, practice, and other features. Linear CAI requires neither learner judgement of the need for additional instruction nor re-routing

through instruction that has been ineffective. Since low achievers are more likely to require the complete sequence of instruction, and are not likely to require, or profit from, the multiple options and decision points of more advanced learners, they may need different, more basic instructional features. In effect, the initial "pass" through the instruction may be the most effective for low achievers, rendering multi-optioned and heavily branched CAI of little additional benefit. Based upon the findings of the present study, simplified but powerful linear designs, that combine learning effectiveness and efficiency, may be the most desirable option for low achievers.

Of further interest was the lack of influence exerted by the CAI strategies compared with the more powerful prior achievement history of the learner. The test score variance-accounted-for by the different CAI strategies was roughly one percent. Prior achievement, on the other hand, accounted for approximately 30 percent of the observed score variance. Clearly, the impact of different control strategies in the face of prior learning was inconsequential. Even if reliable learning differences among control strategies could be obtained, it is unlikely that such a strategy would be substantially more efficient than a linear strategy.

In cases where the information to be learned is sufficiently important, the cost of additional development and instructional time may be warranted. Under most circumstances, however, this is not the case.

In most public educational settings, for example, skills and concepts are taught through a variety of means. CAI is rarely used as the primary or sole instructional delivery system, assuming instead a supplementary function. It seems impractical to expect that that the significant additional expense of high cost, low gain CAI should be assumed given the relatively small increments such designs produce versus simple, but powerful, linear designs. The most straightforward and inexpensive design strategies will likely yield the most efficient solutions for low achievers, and are likely to be more readily designed, produced, and installed into typical instructional settings.

The sensitivity of the achievement classifications used in the present study to differences in learning is also important. Several effects involving the prior achievement levels of the students were obtained, suggesting that considerable heterogeneity existed within presumably "low level" tracked classes. Educators have often argued that remedial classes, such as those used in this study, provide homogeneous learners with respect to instructional style, skill levels, learning rate, and learning style. These arguments may be weakened in view of the findings of this study. Even within the restricted range of test scores defined as prior achievement, the more able learners obtained significantly higher rule recall scores, were quicker and more efficient during acquisition, and applied mathematics rules to numeric problems with proportionately greater accuracy than the very low

achievers. The universal instructional approach often sought for low achievers may be not only impractical, but misleading as well.

The absence of effects for sex of student may indicate that male and female low achievers are more similar than their normal and high achieving counterparts. The male-female achievement differences, beginning roughly at the academic grade level of the students participating in the present study, are well-documented for the general population. For low achievers, however, gender does not appear to differentiate the effectiveness of control strategies, or to affect the magnitude or efficiency of mathematics learning.

The true effects of varied CAI instructional control strategies on the mathematics rule learning of low achieving junior high school students may be related more to the efficiency than the magnitude of learning. The methods employed, and questions addressed, in this study have permitted the inclusion of two important practical instructional dimensions not typically evaluated: time and efficiency. These are important dimensions, and represent a departure from the manner in which learning and instruction issues are typically studied. Perhaps future attempts to study the effects of CAI and other instructional delivery systems will move closer still to the merging of empirical and practical concerns.

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Table 1

Mean Scores for Rule Recall and Rule Application Achievement

Prior Achievement	Rule Recall AC	LC	NC	TOTAL	Rule Application AC	LC	NC	TOTAL
				Immediate Test				
Low								
Female	6.0	5.3	4.0	5.1	7.5	7.3	5.3	6.8
Male	4.4	4.0	4.5	4.3	6.4	6.0	6.0	6.2
Below Average								
Female	7.8	4.7	5.5	6.1	11.3	8.0	10.0	9.9
Male	6.3	6.5	7.0	6.7	8.7	9.3	11.3	10.0
Total								
Female	6.9	5.0	4.9	5.6	9.4	7.6	8.0	8.4
Male	5.1	5.5	6.0	5.6	7.3	8.0	9.2	8.2
				Retention Test				
Low								
Female	4.3	4.3	5.0	4.5	8.0	5.8	5.0	6.2
Male	3.8	4.8	4.0	4.2	6.8	5.0	5.0	5.8
Below Average								
Female	6.3	3.8	5.0	5.0	11.7	6.7	7.8	8.6
Male	6.3	5.8	5.5	5.8	9.3	10.0	8.2	9.1
Total								
Female	5.3	4.0	5.0	4.8	9.8	6.1	6.6	7.4
Male	4.8	5.3	5.0	5.0	7.8	7.8	7.1	7.5

Note. AC - Adaptive Control LC - Learner Control with Advisement

NC - No Control

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Table 2

Mean Scores for Rule Recall and Rule Application Learning Efficiency

Prior Achievement	Rule Recall AC	LC	NC	TOTAL	Rule Application AC	LC	NC	TOTAL
				Immediate Test				
Low								
Female	.42	.33	.50	.41	.52	.45	.55	.50
Male	.32	.21	.57	.35	.49	.33	.60	.47
Below Average								
Female	.75	.29	.58	.54	1.07	.44	1.08	.89
Male	.67	.55	.94	.74	.98	.82	1.54	1.16
Total								
Female	.59	.31	.55	.48	.80	.45	.85	.70
Male	.45	.40	.82	.56	.68	.60	1.23	.84
				Retention Test				
Low								
Female	.34	.27	.63	.40	.62	.38	.48	.48
Male	.27	.25	.46	.31	.51	.28	.56	.44
Below Average								
Female	.63	.22	.51	.46	1.17	.42	.80	.80
Male	.65	.48	.74	.63	1.02	.80	1.16	1.00
Total								
Female	.48	.25	.56	.43	.89	.40	.66	.64
Male	.41	.38	.65	.48	.70	.57	.96	.75

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Figure Caption

Figure 1. Mean achievement for below average and low students on rule recall and rule application tests.

Figure 2. Mean learning efficiency for below average and low students on rule recall and rule application tests.

Figure 3. Mean achievement for no control, adaptive, and learner control strategies on immediate and retention tests.

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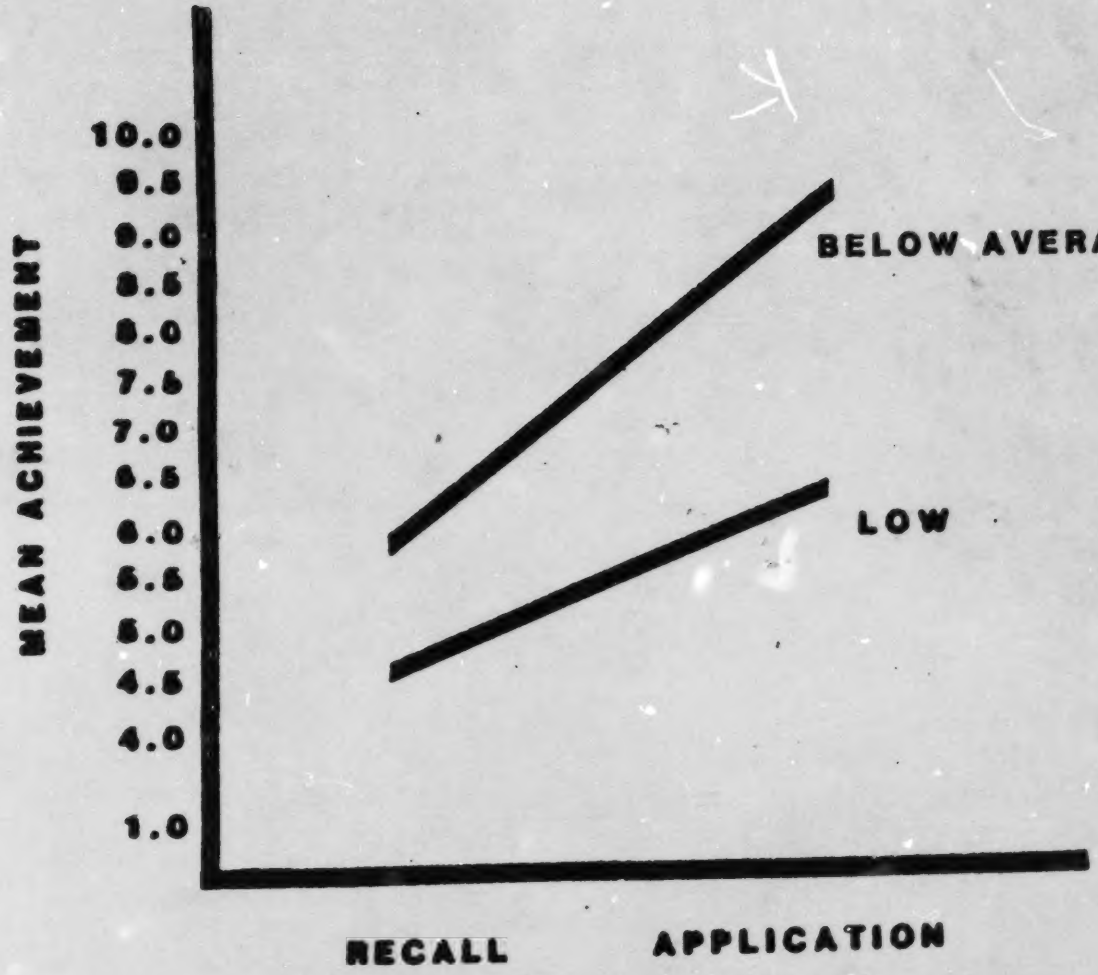

Figure 2

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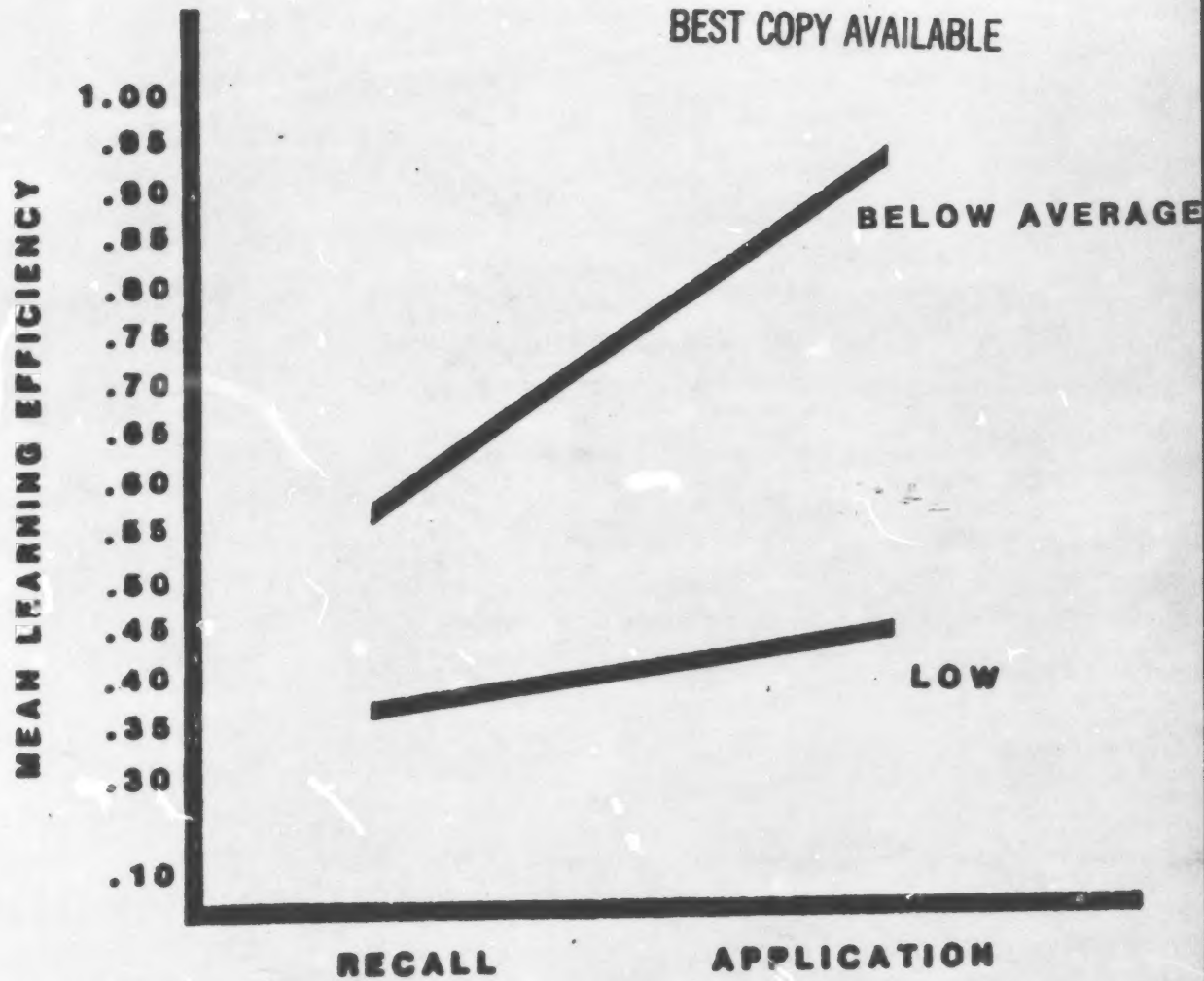

Figure 3

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